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| To: | Mike Trojan, Minnesota Pollution Control Agency  |
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| Date: | April 23, 2020 |
| Subject: | P8 Street Sweeping Modeling |

The Minnesota Pollution Control Agency (MPCA) is developing a method for crediting street sweeping that will provide credit for phosphorus removal, with eventual incorporation into the Minnesota Stormwater Manual. The Stormwater Manual is used by stormwater practitioners to make decisions related to stormwater management, such as selecting appropriate best management practices, understanding stormwater regulatory requirements, and determining pollutant and stormwater volume reductions associated with implementation of different stormwater management practices.

The primary team tasked with developing the crediting method includes the MPCA, University of Minnesota (U of M) and Tetra Tech, with support from the technical team consisting of local municipalities, state staff and consultants. One of the crediting methods under exploration is using simulation modeling to estimate phosphorus removal in leu of more direct monitoring methods. This memorandum provides a summary of a series of P8 (Program for Predicting Pollution Particle Passage through Pits, Puddles, and Ponds) stormwater models used to estimate phosphorus load reduction resulting from street sweeping in four municipalities in the greater Minneapolis, MN region.

A challenge of using simulation models is that the algorithms representing pollutant generation and transport in storm runoff, as well as the impact of street sweeping, are themselves uncertain. In addition, results depend heavily on parameter selection within the model. To provide a basis for comparing P8 results to real world data, the models were configured to represent 2019 street sweeping operations for routes with focused data collection efforts conducted by U of M in support of the larger project. The expectation is that the model results are likely to be biased (low or high) relative to the phosphorus reductions measured by U of M. The team will then assess whether the model can be used within the crediting framework, with an appropriate bias adjustment factor.

# Overview of P8 Model

The P8 Urban Catchment Model is a physically based continuous stormwater quantity/quality model. P8 is capable of predicting the generation and transport of stormwater runoff and associated pollutants (using dissolved fractions and sediment association with four particle size classes) from urban watersheds. P8 simulates pollutant transport and removal in a variety of BMPs including street sweeping. P8 provides loading estimates based on data collected as part of the EPA National Urban Runoff Pollutant (NURP) program. Key inputs include meteorology (hourly rainfall and daily temperature), watershed conditions, and particulate and pollutant loading information.

Watershed runoff is predicted using the curve number method. The user provides various characteristics including watershed area, pervious composite curve number, indirectly connected impervious area fraction, directly connected impervious fraction, impervious depression storage, and two factors that influence initial abstraction in addition to depression storage. Some additional scaling factors are provided as well.

Pollutant mass in runoff is governed by buildup/washoff equations for impervious surfaces and concentration-runoff intensity curves for pervious surfaces. P8 requires the user to specify characteristics for the five modeled particle size fractions (“particle parameters”) and pollutant particle composition associated with each (“water quality components”). These parameters establish how particles are generated by watersheds, how particles are removed by BMPs, and the amount of pollutant associated with each particle class. P8 contains a default particle file as well as two particle files based on findings from the EPA NURP study. Minnesota guidance for using P8 (MPCA, 2019) recommends using the NURP 50th percentile particle parameters and water quality components files, which were used for this modeling project. Particle fractions and associated sediment characteristics are shown in Table 1. Note that the particle classes are focused on sediment that is readily transported in stormwater runoff; courser sands tend not to be mobilized under most storm event conditions.

Table 1. P8 Particle Fractions and Sediment Assumptions

|  |  |  |  |
| --- | --- | --- | --- |
| Particle Fraction | Size, µm | Percent of TSS | USDA Size class |
| P0% | N/A\* | 0% | N/A\* |
| P10% | 2 - 8 | 20% | Clay, Very fine silt |
| P30% | 8 - 20 | 20% | Fine silt, Medium silt |
| P50% | 20 - 60 | 20% | Medium silt, Course silt |
| P80% | 60 - 200 | 40% | Very fine sand, Fine sand |

\* used for dissolved pollutants

In watershed inputs, the user can specify street sweeping scheduling (start date, end date, and weekly sweeping frequency) and the fraction of directly connected impervious area that is vacuum swept versus not vacuum swept. Percent removal efficiencies for each particle class are specified in the particle file. In the more recent releases of P8 (beginning with 3.4 in 2007), estimates of street sweeper efficiency are based on research conducted in Wisconsin in 2007 (Table 2). Note that the values are specified only for vacuum sweeping, since the research suggested that regenerative air and broom sweeping have no impact (or even a negative impact) on loads for the particle classes transported in stormwater runoff.

Table 2. Percent removal of available particle fractions during sweeper passes in P8

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Particle Fraction | P0%  | P10% | P30% | P50% | P80% |
| Current Values | 0 | 0 | 0 | 5 | 15 |

# P8 Model Inputs

The models were configured to represent streets only (i.e., no pervious area), since the study questions are focused on pollutant load reductions from street sweeping. We used model parameters consistent with MPCA guidance for P8 (MPCA, 2019). MPCA does not provide specific recommendations for depression storage and the impervious runoff coefficient, so values for “Smooth-Textured Streets” from P8 guidance were used (0.022 in and 0.701, respectively).

For each combination of municipality and route, two P8 runs were performed – one without street sweeping, and one with street sweeping. The difference in loads between the untreated and treated watershed was calculated. Watershed area was set to 1,000 acres to provide sufficient resolution to calculate phosphorus reduction (due to rounding when a smaller watershed area was used). Final results are normalized to unit area (per acre) values. The simulations with street sweeping were configured to represent 100% treatment of the entire street area. In practice, sweepers generally cover less than the full street width (except for special runs targeting snowmelt debris and autumn leave fall), so the results reflect reductions for the swept areas only.

For hourly precipitation and daily mean air temperature, we utilized the MetTool developed by Tetra Tech (2020) for producing meteorological time series to HSPF watershed models. The MetTool uses PRISM (Parameter-elevation Relationships on Independent Slopes Model; Daly et al., 2008, 2015) and NLDAS-2 (North American Land Data Assimilation System; Mitchell et al., 2004) gridded datasets, which are based on a combination of weather station data, satellite and Doppler radar data, and orographic information. Separate precipitation and air temperature inputs were developed for each of the four municipalities, spanning Jan 1, 2018 through Dec 31, 2019. The first year of the simulation (2018) provided a spin-up period for load buildup and washoff to stabilize. Model output was collected during Jan 1 – Dec 31, 2019.

U of M provided data for each municipality and route, including sweeping date(s) and type of sweeping equipment. Other narrative information was provided for some routes including street type (residential versus downtown), and sweeping intensity (e.g., entire street swept during one date during the fall to target leave fall). We synthesized the data into the required P8 inputs: sweeping annual start and stop dates (as mmdd, which addresses suspension of sweeping during the winter), and weekly sweeping frequency (calculated as the number of 2019 sweeping passes divided by number of weeks between start and stop dates). The data are shown in Table 3.

Table 3. P8 Street Sweeping Input Values

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Municipality | Route Name | State Date | End Date | Pass Count | Frequency (x/wk) |
| Forest Lake | FL 1 | 4/25/2019 | 10/7/2019 | 12 | 0.509 |
| Forest Lake | FL 2 | 4/29/2019 | 10/8/2019 | 12 | 0.519 |
| Forest Lake | FL 3 | 4/30/2019 | 10/9/2019 | 12 | 0.519 |
| Forest Lake | FL 4 | 5/7/2019 | 9/16/2019 | 6 | 0.318 |
| Forest Lake | FL 5 | 5/2/2019 | 10/10/2019 | 6 | 0.261 |
| Forest Lake | FL 6 | 5/9/2019 | 9/25/2019 | 6 | 0.302 |
| Minneapolis | Linden Hills | 2/4/2019 | 12/2/2019 | 11 | 0.256 |
| Minneapolis | Theo-Wirth, Cedar Lake, Dean, LOI Parkway | 2/12/2019 | 12/10/2019 | 11 | 0.256 |
| Minneapolis | Carag | 2/18/2019 | 12/16/2019 | 11 | 0.256 |
| Minneapolis | Kenwood/Cedar-Dean-Isle | 2/25/2019 | 12/23/2019 | 11 | 0.256 |
| Minneapolis | Loop Routes- Monday Route and Group A | 2/4/2019 | 12/2/2019 | 11 | 0.256 |
| Minneapolis | Loop Routes- Tuesday Route and Group B | 2/12/2019 | 12/10/2019 | 11 | 0.256 |
| Roseville | Lake McCarrons | 4/20/2019 | 11/3/2019 | 4 | 0.142 |
| Roseville | Lake Como Watershed Area | 4/5/2019 | 10/30/2019 | 4 | 0.135 |
| Roseville | Commercial | 4/1/2019 | 10/28/2019 | 4 | 0.133 |
| Roseville | Lake Owasso | 4/2/2019 | 11/8/2019 | 4 | 0.127 |
| Shoreview | Zone 1 | 4/23/2019 | 10/25/2019 | 5 | 0.189 |
| Shoreview | Zone 2 | 4/13/2019 | 11/18/2019 | 5 | 0.160 |
| Shoreview | Zone 3 | 4/1/2019 | 10/29/2019 | 3 | 0.100 |
| Shoreview | Zone 4 | 4/18/2019 | 9/11/2019 | 2 | 0.096 |
| Shoreview | Zone 5 | 4/3/2019 | 11/18/2019 | 6 | 0.183 |
| Shoreview | Zone 6 | 4/18/2019 | 11/13/2019 | 3 | 0.100 |
| Shoreview | Zone 7 + Zone 8 | 3/25/2019 | 11/13/2019 | 5 | 0.150 |

Note that P8 does not allow for entry of specific sweeping dates, so a limitation of the model is that the simulated sweeping date differs from the true sweeping date when the interval between sweeping events varies. Another limitation of P8 is that vacuum sweeping is the only technology represented by default. We did not attempt to develop alternate efficiency parameters for brush and regenerative air sweepers; sweeping performance studies show considerable variation in design and results and are often skewed to reflect course sediment removal rather than fines that are ultimately transported in storm runoff. In addition, entities seeking to use P8 to obtain credit are likely to use model default performance values.

# Results

Simulation results for each combination of municipality and route are shown in Table 4 for sediment and Table 5 for phosphorus. Sediment percent reduction ranges from 0.14% to 0.90%, while phosphorus reduction ranges from 0.023% to 0.145%. The approximately six-fold difference between sediment and phosphorus percent reduction is a result of two factors: the dissolved component of phosphorus is not reduced by sweeping, and the P8 NURP 50th percentile input file assumes there is no phosphorus association with the P80% particle fraction, which comprises 40% of the sediment load. More recent literature reviews of pollutant sediment association by particle size indicate a significant fraction of phosphorus can be associated with the P80% fraction (Pitt et al, 2017; DeGroot and Weiss, 2008), so relying on older NURP pollutant data could be viewed as a limitation of P8.

P8 predicted annual sediment reduction resulting from street sweeping never exceeds 1% among all of the 2019 scenarios. This reflects several factors, some of which result from limited sweeping frequency and temporal coverage, and some of which reflect P8 assumptions. Annual sweeping passes range from 2 to 12, and most of the municipalities sweep no more than six months during spring – fall, so no removal from sweeping is simulated during early and late months. P8 uses conservative assumptions regarding sweeping performance; when the percent TSS mass by particle fraction from Table 1 is combined with reductions in Table 2, the result is that sweeping can remove no more than 7% of available accumulated sediment. P8 simulated over 80 separate runoff events during 2019 in each of the municipalities, so much of the accumulated sediment was washed off between the relatively infrequent sweeping runs.

Table 4. P8 Sediment Results for Baseline and Sweeping Scenarios

| Municipality | Route Name | Sediment Loading rates (lb/ac/yr) | Percent Reduction |
| --- | --- | --- | --- |
| **Baseline** | **Sweeping** | **Difference** |
| Forest Lake | FL 1 | 555.36 | 550.43 | 4.93 | 0.89% |
| Forest Lake | FL 2 | 555.36 | 550.35 | 5.01 | 0.90% |
| Forest Lake | FL 3 | 555.36 | 550.34 | 5.01 | 0.90% |
| Forest Lake | FL 4 | 555.36 | 552.85 | 2.51 | 0.45% |
| Forest Lake | FL 5 | 555.36 | 552.81 | 2.55 | 0.46% |
| Forest Lake | FL 6 | 555.36 | 552.94 | 2.42 | 0.44% |
| Minneapolis | Linden Hills | 682.37 | 678.46 | 3.90 | 0.57% |
| Minneapolis | Theo-Wirth, Cedar Lake, Dean, LOI Parkway | 682.37 | 678.46 | 3.90 | 0.57% |
| Minneapolis | Carag | 682.37 | 678.46 | 3.91 | 0.57% |
| Minneapolis | Kenwood/Cedar-Dean-Isle | 682.37 | 678.42 | 3.94 | 0.58% |
| Minneapolis | Loop Routes- Monday Route and Group A | 682.37 | 678.46 | 3.90 | 0.57% |
| Minneapolis | Loop Routes- Tuesday Route and Group B | 682.37 | 678.46 | 3.90 | 0.57% |
| Roseville | Lake McCarrons | 633.51 | 631.93 | 1.58 | 0.25% |
| Roseville | Lake Como Watershed Area | 633.51 | 631.88 | 1.63 | 0.26% |
| Roseville | Commercial | 633.51 | 631.85 | 1.65 | 0.26% |
| Roseville | Lake Owasso | 633.51 | 631.93 | 1.57 | 0.25% |
| Shoreview | Zone 1 | 612.15 | 610.04 | 2.12 | 0.35% |
| Shoreview | Zone 2 | 612.15 | 610.23 | 1.92 | 0.31% |
| Shoreview | Zone 3 | 612.15 | 610.89 | 1.26 | 0.21% |
| Shoreview | Zone 4 | 612.15 | 611.28 | 0.87 | 0.14% |
| Shoreview | Zone 5 | 612.15 | 609.85 | 2.30 | 0.38% |
| Shoreview | Zone 6 | 612.15 | 611.01 | 1.14 | 0.19% |
| Shoreview | Zone 7 + Zone 8 | 612.15 | 610.16 | 1.99 | 0.32% |

Table 5. P8 Phosphorus Results for Baseline and Sweeping Scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| Municipality | Route Name | Phosphorus Loading rates (lb/ac/yr) | Percent Reduction |
| Baseline | Sweeping | Difference |
| Forest Lake | FL 1 | 1.92607 | 1.92331 | 0.00276 | 0.143% |
| Forest Lake | FL 2 | 1.92607 | 1.92327 | 0.00280 | 0.145% |
| Forest Lake | FL 3 | 1.92607 | 1.92327 | 0.00280 | 0.145% |
| Forest Lake | FL 4 | 1.92607 | 1.92467 | 0.00140 | 0.073% |
| Forest Lake | FL 5 | 1.92607 | 1.92465 | 0.00142 | 0.074% |
| Forest Lake | FL 6 | 1.92607 | 1.92472 | 0.00135 | 0.070% |
| Minneapolis | Linden Hills | 2.37398 | 2.37182 | 0.00216 | 0.091% |
| Minneapolis | Theo-Wirth, Cedar Lake, Dean, LOI Parkway | 2.37398 | 2.37181 | 0.00217 | 0.091% |
| Minneapolis | Carag | 2.37398 | 2.37181 | 0.00217 | 0.091% |
| Minneapolis | Kenwood/Cedar-Dean-Isle | 2.37398 | 2.37179 | 0.00219 | 0.092% |
| Minneapolis | Loop Routes- Monday Route and Group A | 2.37398 | 2.37182 | 0.00216 | 0.091% |
| Minneapolis | Loop Routes- Tuesday Route and Group B | 2.37398 | 2.37181 | 0.00217 | 0.091% |
| Roseville | Lake McCarrons | 2.19744 | 2.19657 | 0.00087 | 0.040% |
| Roseville | Lake Como Watershed Area | 2.19744 | 2.19655 | 0.00089 | 0.041% |
| Roseville | Commercial | 2.19744 | 2.19653 | 0.00091 | 0.041% |
| Roseville | Lake Owasso | 2.19744 | 2.19658 | 0.00086 | 0.039% |
| Shoreview | Zone 1 | 2.10293 | 2.10176 | 0.00117 | 0.056% |
| Shoreview | Zone 2 | 2.10293 | 2.10187 | 0.00106 | 0.050% |
| Shoreview | Zone 3 | 2.10293 | 2.10223 | 0.00070 | 0.033% |
| Shoreview | Zone 4 | 2.10293 | 2.10245 | 0.00048 | 0.023% |
| Shoreview | Zone 5 | 2.10293 | 2.10166 | 0.00127 | 0.060% |
| Shoreview | Zone 6 | 2.10293 | 2.10230 | 0.00063 | 0.030% |
| Shoreview | Zone 7 + Zone 8 | 2.10293 | 2.10183 | 0.00110 | 0.052% |

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